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Ninth Bimonthly Report on the Automatic Transmitter Program

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ORIGINAL CL BY 235979
☐ DECL ☐ REVW ON 2010
EXT BYND 6 YRS BY SAME
REASON 3 d (3)

DOC 44 REV DATE 14 APR 1980 BY 018373
ORIG COMP 33 OPI 56 TYPE 30
ORIG CLASS M PAGES 13 REV CLASS C
JUST 22 NEXT REV 2010 AUTH: HR 70-2

Period: 8-Jan. to 8-March - 1960

[redacted] 25X1

Prepared by: [redacted] 25X1

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Declassified in Part - Sanitized Copy Approved for Release 2012/02/08 : CIA-RDP78-03424A000800010043-7

I Purpose

See Bimonthly Report No. 1.

II Abstract

In this report a description is given of the work which has been carried out on the automatic impedance unit in order to reduce the time necessary for tuning and to obtain satisfactory operation with relatively low RF output power. A description is also given of the modified RF circuitry which has been developed. The purpose of this modification is in order to provide an output which contains only odd harmonics. By using a 3 band system, it is possible to suppress, by fixed frequency filters, the odd harmonics of output frequencies from 3-30 mc. It would not be possible to do this in only 3 bands if the even harmonics were also present.

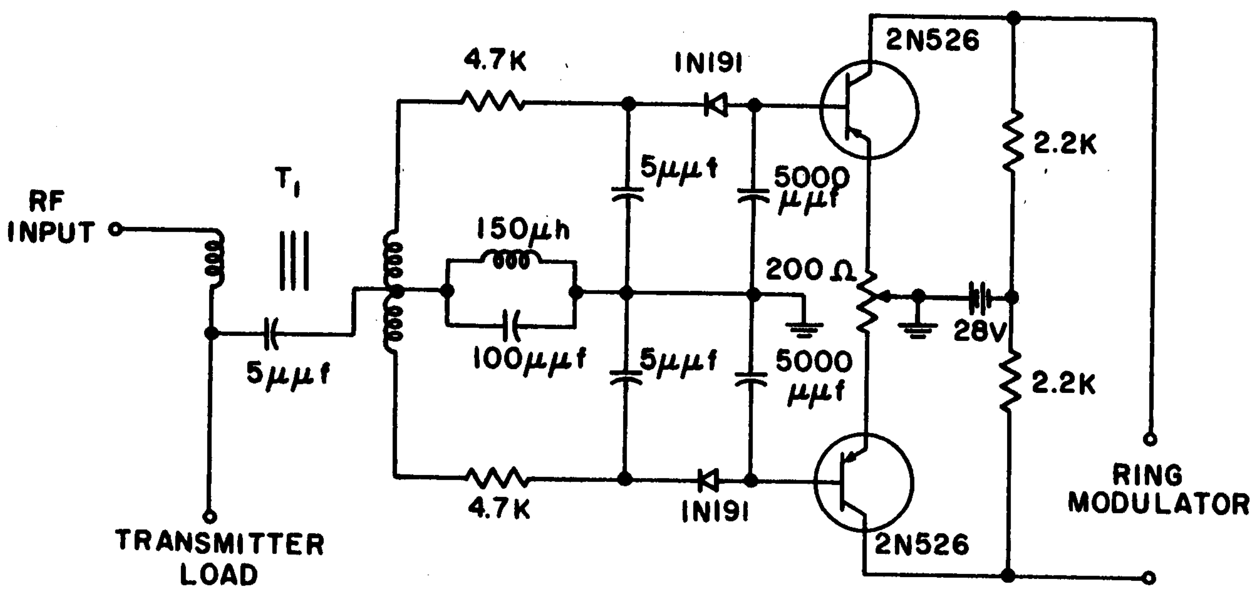
During the past two months, construction of the transmitter in finished form was continued. Considerable thought has, consequently, been given to mechanical considerations as well as to auxiliary circuitry. The auxiliary circuitry is concerned with such functions as turning off the servo system after the matched condition has been attained, providing facilities for "break in" operation and ensuring that the tuning cycle is automatically re-started whenever the frequency of operation is changed by inserting a different crystal. A description of this work is included in this report.

III Factual Data

(a) Automatic Impedance Matching

During the past reporting period the work on the automatic impedance unit has been concentrated mainly on (i) reducing the time required for tuning and (ii) achieving satisfactory operation with RF levels of about 250 milliwatts. The need to operate at relatively low power levels was due to the limitations imposed by the available transistors.

The automatic impedance matching unit as demonstrated to the customer required a maximum of $2\frac{1}{2}$ minutes for tuning. An important factor in determining the amount of time required for tuning is the mechanical construction of the coil. The process of winding and unwinding the turns from the coil is a relatively slow one. However, the allowable coil speed is not solely determined by its mechanical properties. Proper operation of the system requires that, while the coil is tuning, the capacitor must maintain an admittance phase angle which is very nearly zero. Thus, the coil speed can be increased only if the capacitor response is sufficiently rapid. The initial attempt to increase the coil speed by a factor 3 resulted in system instability. The primary source of this instability was due to an inadequate capacitor response. The speed of the capacitor was increased by changing its speed reduction from 3000:1 to 100:1. However, since the increase in capacitor speed also resulted in a decrease in phase error sensitivity (because of increased torque requirements), it was necessary to insert additional D.C. gain in the phase sensor circuitry (as shown in Figure 1). The theory of operation of this circuit is basically the same as that described in the Third Bimonthly Report. The 4.7 KΩ resistors and 5 $\mu\mu$f capacitors were inserted to compensate for the frequency dependence of the phase error signal. (The signals induced in the transformer are increasing functions of frequency.) The two 2N526 transistors provide balanced D.C. amplification to the error signal which is subsequently applied to the ring modulator.



PHASE SENSING CIRCUIT WITH INCREASED SENSITIVITY

FIGURE 1

The servo loop has now been stabilized with component speeds that result in a maximum tuning time of 50 seconds. Satisfactory operation has also been achieved with RF power levels as low as 200 milliwatts.

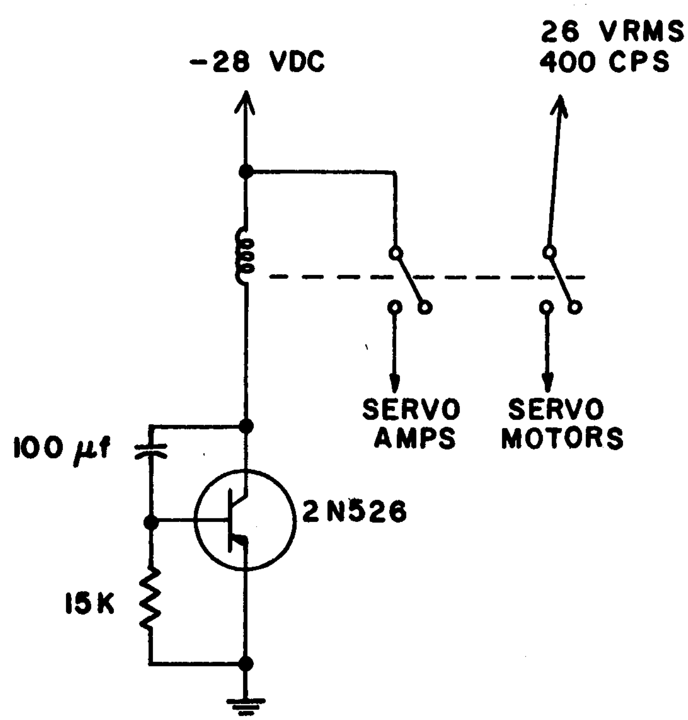
It was stated in the previous report that the impedance matching unit did not function properly when it was connected to the transistor RF circuitry. This difficulty was attributed to the presence of harmonics in the RF signal. Modifications of the RF circuitry were investigated in an attempt to improve this situation. During the course of these investigations a new transistor, the 2N706, became available. This transistor is now being used in a circuit which has produced 2 watts of RF power. Although the harmonic content of this signal is still too great to allow proper operation of the automatic impedance matching unit, the signal contains only odd harmonics. This allows the waveform to be filtered if the 3-30 mc range is divided into three bands. It is expected that the three low pass filters can be added to the RF circuitry with a relatively small increase in the overall complexity and volume requirements. The automatic impedance matching unit has been successfully operated when connected to the filtered RF output.

It should be noted that even though it appears that the RF power level will be about 2 watts, the improved capacitor response is still necessary. Even with 2 watts of RF power, the original capacitor response was not adequate to have allowed the coil speed to have been increased appreciably.

Mechanical considerations have led to some modifications in the impedance matching unit. The use of braided wire in the variable inductor has been found to be superior to solid wire. The braided wire is able to withstand more flexing than solid wire. The change to braided wire requires that, in order to maintain tracking of the wire between the ferrite rod and the brass rod, the grooves in the rods should be made broader and deeper. This was done in the Laboratory Model Shop.

A safety feature has also been added to the impedance matching unit. The clutch which was previously installed on the capacitor prevents any mechanical damage from occurring in the event the capacitor is driven to either its maximum or minimum position. The coil has now been modified to provide a similar protection. The mechanical design of the coil did not lend itself to the addition of a clutch, so a limit switch was added instead. The limit switch will be actuated if the coil is driven to its minimum position. This then trips the preposition relay, which causes the coil immediately to start winding back toward its maximum. (The other logic circuitry automatically prevents the coil from being driven all the way to its maximum position.) Actually,if a proper load (one whose impedance lies within the modified impedance plane area) is connected to the transmitter, the coil will never be driven to either extreme. However, in the event an improper load is connected to the transmitter, no damage will be incurred.

In order to avoid unnecessary power consumption, it is desirable to turn off the servo system power supplies after the tuning of transmitter has been accomplished. A simple way of accomplishing this is to channel the servo system power through a relay which automatically opens when a time interval sufficient to allow tuning has elapsed. This is accomplished in the circuit of Figure 2. The 2N526 remains "on" until the 100 μf capacitor has been charged. The circuit parameters result in the relay being opened after about 70 seconds has elapsed. (The tuning is accomplished in no more than 50 seconds.)



SERVO POWER TIMING CIRCUIT

FIGURE 2

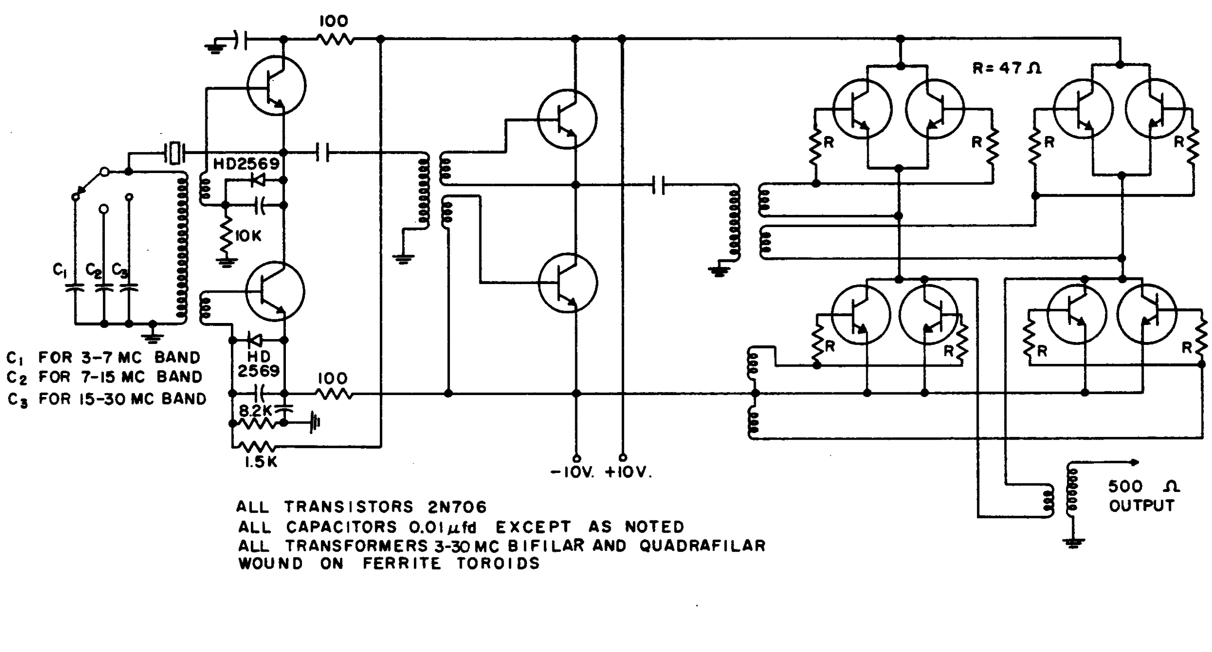
Final construction is in progress on the automatic impedance matching unit subassembly circuitry. This construction is being carried out with emphasis on the achievement of a small volume.

(b) The RF Circuitry

Figure 3 shows the circuitry of the transmitter itself as distinct from the antenna matching network and the auxiliary circuitry. It will be seen that the oscillator stage uses two transistors in a balanced configuration, with a crystal connected in the feedback path. A switch is used which selects an appropriate capacitor according to which of the three bands, into which the 3-30 mc range is divided, it is desired to use. The feedback transformer is broadly tuned to cover the whole of whichever band is selected.

The output of the oscillator is coupled via a broadband toroidal transformer to the push-pull driver stage. Keying will be done in the driver stage which is, in turn, coupled to the output stage, consisting of eight transistors arranged in a bridge configuration. In order to obtain the maximum output power, the transistors in the output stage are operated as RF switches. According to which transistors are turned on and which are turned off, the current from the supply flows through the load in one direction or the other. By switching the transistors on and off at rates varying from 3-30 mc, an AC load current of appropriate frequency is produced. This method of operation has three distinct advantages.

(i) The output waveform contains the fundamental and only odd harmonics. Consequently, by dividing the 3-30 mc range into three bands, it is possible to obtain an ultimate output consisting only of the fundamental by the use of one fixed frequency low pass filter in each band. This would not



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3-30 MC CRYSTAL CONTROLLED TRANSMITTER RF CIRCUITRY

FIGURE 3

be possible with an output waveform which included even harmonics, such as that obtained from a Class C stage. In this case the second harmonic of the low frequencies in the band would fall below the upper frequency limit of the band.

(ii) Since the transistors are operated as switches the power dissipated in them is very small - they either have, ideally, voltage across them but no current through them or current through them and no voltage across them. It is consequently possible to use transistors with quite modest power ratings but excellent high frequency characteristics.

(iii) The power output is essentially constant over the frequency range from 3-30 mc. As long as the drive is sufficient over this range to ensure that the transistors are driven from cut off to saturation, the power in the load is a function of the power supply voltage and not the gain of the transistors at the particular frequency of operation.

The RF circuitry is being constructed on a small board which is bolted to an aluminum heat sink. The transistors, the cases of which are electrically "hot" project from one side of the board into recesses in the heat sink block. In order to provide thermal conduction between the transistor cases and the heat sink,a small quantity of silicon oil is placed in each of the recesses. Around each transistor case a rubber "O" ring is fitted which, in turn, mates with the heat sink. It is anticipated that an RF power output of about two watts can be achieved without any dangerous rise in transistor temperature.

IV Conclusions

As a result of the modifications made to the impedance matching network, under the worst conditions the length of time necessary for tuning has been reduced from $2\frac{1}{2}$ minutes to 50 seconds. A previous attempt to reduce the tuning time resulted in instability. This problem has now been solved. It was found necessary to include additional DC amplification in the servo loop in order to take care of the reduced RF power output which it appeared would be supplied from presently available transistors and to compensate for the reduction in sensitivity resulting from the decrease in the torque multiplier ratio. The torque multiplier ratio was changed in order to speed up the operation.

Difficulty was reported previously, arising from the presence of harmonics in the RF output which caused malfunctioning of the sensing circuits. The recent availability of 2N706 transistors has made possible the design of an output stage, the output from which contains only the fundamental and odd harmonics of the desired frequency. It is, consequently, possible by dividing the 3-30 mc range into three bands, to remove the odd harmonics by means of one fixed filter in each band. This would not be possible if even harmonics were present. Using these transistors it is anticipated that an RF output power of about 2 watts can be obtained over the range from 3-30 mc.

Various mechanical modifications have been made to the impedance matching unit in order to make it more reliable and give it greater immunity to damage as a result of accidental misuse. Circuit features have also been worked out in order to render operation of the transmitter as "foolproof" as possible and to keep the power drain to a minimum. One such feature automatically turns off the power to the servo system after the tuning operation has been completed. One advantage of using a mechanical impedance matching system results from its inherent memory. With an electrical system, a memory function would have to be performed which would probably result in a continuous power drain. The overall circuit design is now essentially complete and construction of the finished equipment is proceeding.

V Future Plans

From now until the completion of the program, the work will consist almost entirely of packaging. While it is understood that under the present program a transmitter will be delivered which does not represent a final mechanical design, an effort is being made to construct the equipment with as small a physical volume as can be readily achieved, without the fabrication of a large number of special components. It is intended that the equipment be made relatively accessible so that evaluation tests may be carried out on various portions of the circuitry without undue risk of damage to adjacent circuitry.

VI Identification of Key Technical Personnel

See previous reports.